MODULAR EMBEDDED SYSTEM

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Abstract: National Instruments Corp is a company in the business of virtual instrumentation with a strong focus in embedded measurement and automation. Ever-increasing customer demand to do measurements, communicate and access information anytime, anywhere, puts a lot of pressure on vendors of instrumentation to be capable of delivering technologies that offer high-performance, flexibility and robust functionality - all in the small-size, low-power framework of portable, battery-powered products. We, the group of people who author this paper, are part of National Instruments' world wide research effort on embedded measurement and computing. This paper describes the research to produce a wireless, battery powered data acquisition device, that is easy to program and powerful enough to perform complex data filtering and analysis.

Key Words: LabVIEW programmable, XScale processor, Wireless Ethernet.

1. INTRODUCTION

Advances in processor architectures, small footprint Operating Systems, and availability of LabVIEW engines for execution of graphical code on processors other than traditional X86 architectures, are the three very important technologies that powered the research, and made the Modular Embedded System possible. We have designed and prototyped an optimal embedded measurement device, the Wireless DAQ that has the following capabilities:

1) Ethernet connected via 802.11b wireless PCMCIA card or wired Ethernet card;
2) Can be programmed from LabVIEW Host environment;
3) Runs application in self-standing mode;
4) Performs data acquisition, data analysis, and data communication;
5) Battery powered, with efficient power consumption.

The Wireless DAQ device has two components:

- A controller board with a 400MHz XScale processor from Intel with PCMCIA slot for wireless communication;
- A DAQ board attachment, of Multifunctional type, that acquires data from sensors and sends the data to the controller board via an internal data bus. [1]

The Wireless DAQ hardware (figure 1) is built around an XScale Intel processor, and software is the versatile Linux operating system accompanied by the

LabVIEW Real-Time for ARM processors.

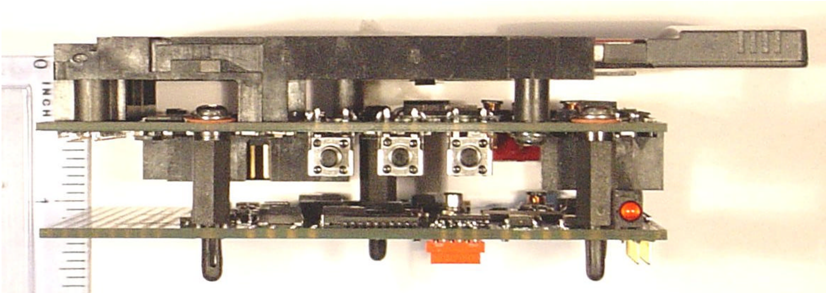

Figure 1 – Side view of wireless DAQ

XScale processor Technology:

The XScale is a low power, ARM family, 400 MHz processor, with a seven-stage pipeline that is widely used in PDA devices from different manufacturers. This processor supports Linux, PocketPC and Windows CE operating systems. [2]

Embedded Linux Technology:

Embedded Linux found initial traction in networking devices like gateways and firewalls as well as entertainment products. Now Linux is making inroads across the board in a wide range of devices and systems, from hand-held consumer devices to industrial products to large defense programs. [3]

LabVIEW Real-Time Technology:

LabVIEW on the Host computer and LabVIEW Real-Time engine for target devices offer a unique combination of graphical development environment and capability of downloading application on target devices for embedded (independent from Host) execution and storage.

2. THE WIRELESS DAQ DEVICE, HARDWARE ARHITECTURE

The Wireless DAQ device consists of two stacked boards - the processor board and the data acquisition board, - connected via an SPI bus.

2.1. The Processor board

The Processor board is built around the PXA255 processor, an integrated system-on-a-chip microprocessor for high performance, low power portable handheld and handset devices. The PXA255 is an Intel XScale family processor with on-the-fly frequency scaling and power management to provide very good MIPs/mW performance. The PXA255 is compliant with the ARM Architecture Version 5TE instruction set (without floating point instructions). [4]

The following is the Wireless DAQ Processor Board feature list that is implemented in this device:

- Processor, PXA255 XScale, 400MHz core; [5]
- Power supply: 3.7V-5V input range, DC / battery switching;
- Memory – two options: 8/32MB SDRAM and 4/16MB Flash;
- PCMCIA: +3.3V, 16-bit card (not +5V compatible or 32bit);
- Communication:
    - Ethernet with 802.11b PCMCIA card,
    - Serial port: Serial RS-232, full: RTS, CTS, DTR, DSR, DCE, RI;

- Real Time Clock (RTC);
- E2PROM for configuration or DAQ calibration;
- 8 switches for configuration;
- Battery voltage monitoring;
- SPI with external clock (5MHz);
- Expansion connector for: I2C bus, reset, pulse width-modulator, GPIO.

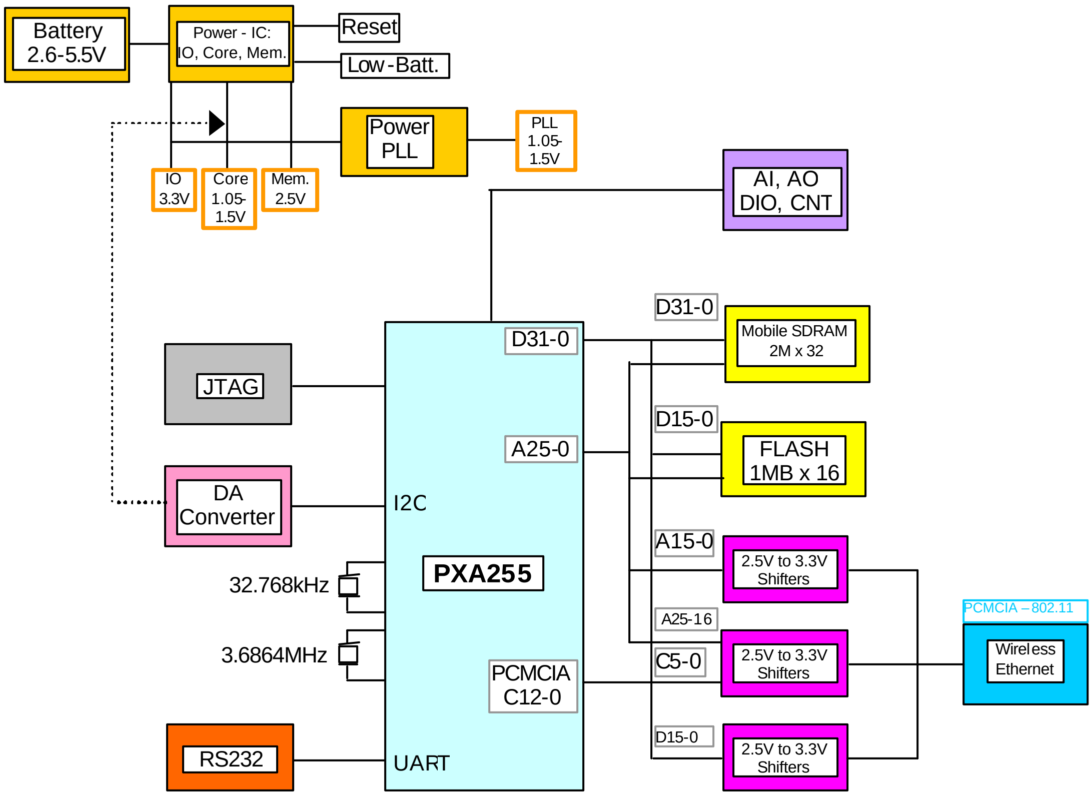

Figure 2 – Block diagram of processor board

This architecture for a processor board and features list is a good compromise (as of today's technology) between power consumption and computational power that is needed to perform advanced acquisition and analysis on measurement data. We have worked previously with the StrongARM processor from Intel, so we knew very well what to expect in terms of processing power from XScale. Extensive Linux support for the XScale processor was also very helpful. This processor board is the equivalent of a PDA board without an LCD display, similar to the Zaurus SL-5600 series from Sharp, for example. The fact that the XScale chip is used in a large variety of PDAs is also an advantage because we are using off-the-shelf "computer" based components that are easy to find, mass market produced, and well supported.

2.2. The DAQ board

The DAQ board daughter card is built around the C8051F124 Mixed-Signal ISP Flash MCU (*64kB flash and 8kB SRAM*). The board offers the following functionality:

- Analog input: 8-ch, 12-bit, 50kHz, two ranges ±10V; ±2.4V, with option: external conversion start;

- Analog output: 2-ch ±2.5V range;
- Digital Output: 8-ch, LVCMOS (+3.3V);
- Digital Input: 8-ch, LVCMOS (+3.3V);
- Timer: 2-ch, T2, T4;
- Digital bus to the controller board. [6]

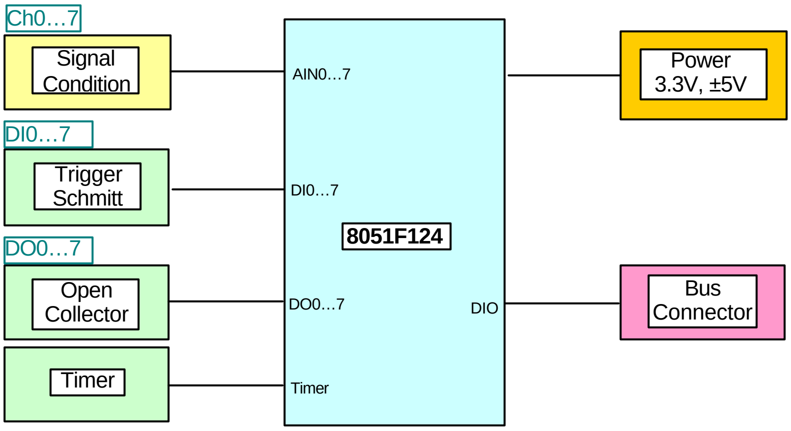

Figure 3 – Block diagram of DAQ board

This architecture for a DAQ board attachment to a processor card is ideal for situations where 12-bit or lower ADC precision is required. For higher DAQ accuracy an improved discrete analog front end could be used. On-board intelligence on the DAQ board is necessary for two reasons:
- To run the internal DAQ API, that is a set of data acquisition functions covering en entire spectrum of acquisition methods from single point to asynchronous waveform types;
- To send the acquired data, via SPI DMA transfers, to the processor board.

The Cygnal C8051F124 part turned out to be very well suited to the above needs, it is also low power and easy to program.

3. THE WIRELESS DAQ DEVICE, SOFTWARE ARHITECTURE

Wireless DAQ board functionality is implemented by three software components running concurrently. These components are:

- The OS (Linux),
- The DAQ API device driver,
- The LabVIEW Real Time Engine.

Memory requirements for the above components are:

- The Linux kernel (up to 600 Kbytes), and a basic Linux environment (~800 Kbytes),
- LVRT 7.0 (~ 2.5Mbytes) and LV Advanced Analysis (~800 Kbytes).

The minimum memory requirements for this LabVIEW package are 3.5 Mbytes of flash memory and 7 Mbytes of RAM.

The OS - Linux distribution installed

Bootloader: Redboot September 2003 snapshot.
Kernel: 2.4.19-rmk7-pxa1 with patches.

- Memory footprint ~1Mbyte;
- power management: *idle mode* (reduces power consumption where there is nothing to do); *sleep mode* (if program/user request sleep mode the system enter a state with low power consumption – this mode is leaved by pressing the Wake-up button); *timed sleep mode* (like sleep mode, but it can use either the internal clock or the WakeUp button to leave sleep state);
- Support for Prism based 802.11 (WiFi) cards;
- Fastfloat floating point emulator.

Userland: A custom distribution containing: *C/C++ library*: uClibc 0.9.21; *Busybox 1.0-pre3* – used for basic system utilities; *vsftpd* – ftp server; *thttpd* – httpd server; *utelnetd* – telnet server.

The DAQ API – installed in 8051 RAM memory on the C8051F124.

The LabVIEW Engine: LabVIEW RT 7.0 for ARM processors with Analysis 7.0 for ARM processors.

4. THE APPLICATION

In order to demonstrate Wireless DAQ functionality, the following LabVIEW application (figure 4) has been implemented on the device: acquire a finite (or continuous) waveform (sinus) analog input from ch0 of the DAQ board. Apply an FIR filter on the acquired waveform, and then display, both the real-time signal with power spectrum, and the filtered signal with power spectrum. Repeat these operations inside a Continuous Loop until a STOP button is pressed on the instrument panel. Host LabVIEW VI panel and diagram are shown below.

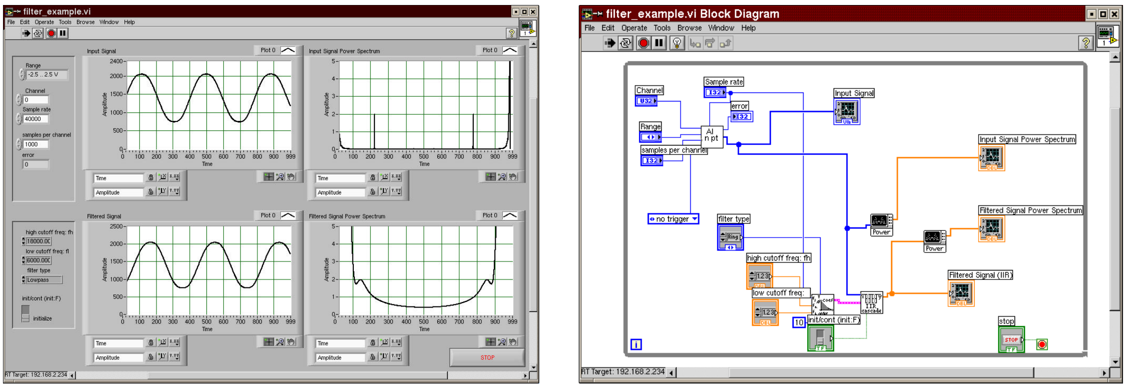

Figure 4 – LabVIEW application for data analysis

Data is acquired using a DAQ API VI then LabVIEW analysis library is used to implement the filtering of data samples. Working in LabVIEW is intuitive and easy, which justifies the effort to port the Analysis Library to the ARM architecture.

When the Run button is pressed, the application VI is sent over 802.11b wireless network gets downloaded in processor memory and starts running on the Wireless DAQ device, with the application panel shown on the Host computer.

Power Tests with a Li-Ion battery (+4.1V, 1400mAh):

- 5h 26min. continuous acquisition at 1KS/sec followed by 802.11b transmission to Host computer, from LabVIEW;

- 4h 29min. continuous acquisition at 50KS/sec followed by 802.11b transmission to Host computer, from LabVIEW.

Table1: Power Consumption

Processor Frequency	Power	Condition
100MHz	164 mW	Linux + VI running
200MHz	202 mW	Linux + VI running
400MHz	271 mW	Linux + VI running
200MHz	1090 mW	Linux + VI running + Ethernet 802.11

A further improvement could be obtained by storing data on a large memory buffer and sending it in large packets from time to time. That would reduce the number of communication sequences thus allowing 802.11's power management to save power. This approach could reduce power consumption to a level that allows 10 – 20 hours of continuous operation with a Li-Ion battery (+4.1V, 1400-3000mAh).

5. CONCLUSION

The Wireless DAQ device is a very powerful cost-effective embedded measurement, storage, and communication device. The fact that it can be programmed from LabVIEW is a big plus because it shortens the time investment in application development. Compared to existing National Instruments products, like PXI instrumentation, and FieldPoint modules, the Wireless DAQ device is lower power, lower cost, and more mobile. The Wireless DAQ device is not a replacement for these much more sophisticated measurement methods, but rather complementary, addressing those users that use Linux, are not afraid of developing complicated applications not only at LabVIEW layer but also at the Linux driver layer. Moreover, the Wireless DAQ device is better suited for situations where custom hardware is needed, the user wants to modify or adapt the hardware, in the concept phase of his application, according to his needs. After the design phase is over he can multiply the setup many, many times. The research emphasizes once again the power of LabVIEW and the validity of the LabVIEW everywhere idea.

6. REFERENCE

[1] National Instruments USA, Internal notes.
[2] Intel Corporation, 2004, http://www.intel.com/design/pca/prodbref/252780.htm
[3] http://www.linuxdevices.com
[4] Intel Corporation, 2004, Intel® PXA255 Processor Developer's Manual, Order Number: 278693-002.
[5] Intel Corporation, 2003, Intel® PXA250 and PXA210 Processors, Order Number: 278534-012.
[6] CYGNAL Integrated Products, Inc. 2003, High-Speed Mixed-Signal ISP FLASH MCU, DS008-0.9b-FEB03.